The Mineral Map of Australia: The realisation of a dream

Thomas Cudahy, Mike Caccetta, Simon Collings, Carsten Laukamp, Matilda Thomas, Cindy Ong, Ian Lau, Andrew Rodger, Rob Hewson, Joanne Chia, Mike Abrams
11 October 2013
ASTER system

1st (only) geoscience-tuned satellite sensor

- Japanese designed/built (ERSDAC now JSS)
- USA satellite platform (TERRA)
- Launched December 1999
- Basic specifications
  - 60 by 60 km image
  - 14 spectral bands:
    - 3 VNIR (Landsat config) @ 15 m
    - 6 SWIR @ 30 m
    - 5 TIR @ 90 m
  - Push-broom for VNIR and SWIR
  - Whiskbroom for TIR
- Significant Instrument/data Issues
  - atmospheric correction, SWIR X-talk, TES
- SWIR module failed 2009
- Data now only available through ERSDAC GDS
  http://www.gds.aster.ersdac.or.jp/gds_www2002/index_e.html
Importance of ASTER for Geosciences

• ASTER is the only operational satellite-borne sensor specifically designed for geoscience/mineral mapping applications;
• The advantage of ASTER over other satellite data are
  • 6 bands in SWIR region to distinguish AlOH, FeOH, MgOH mineral groups;
  • 5 bands in TIR region to distinguish silica, quartz, mafic, carbonate mineral groups;
  • Bands in the VNIR to infer ferric oxides (overlaps with other satellites);
ASTER Mineral Map of Australia Workflow

35,000 L1B ASTER scenes ~10Tb /source/ to 3600 scenes

1. Scene selection, QA scripts. ENVI/IDL code /work/?
   - Visualisation (Analysis) ArcMAP 10
     Multiple parallel sessions

2. Geo-registration, sensor gain, resampling. ENVI/IDL code
   - Exoatmospheric correction
     ENVI/IDL code
   - Ratios
     ENVI/IDL code

3. Cross scene calibration
   R script, c code
   - Threshold
     ENVI
     (Multiple parallel sessions)
   - Mosaicing
     ENVI

4. Conversion to reflectance
   ENVI/ IDL code
   - Information Extraction
     ENVI/IDL code
   - Mosaicing
     ENVI

5. Geoscience product generation
   ENVI/IDL code
   - Validation
     ENVI
     Multiple parallel sessions

Validation
ENVI
Multiple parallel sessions

Candidate scenes

Invert target mask

Automated process
Interactive process
IO intensive
CPU intensive
Iterative
Core workflow
Methodology - Overview

- Scene selection
  - L1B radiance@sensor data
  - where possible summer, cloud free scenes are used.

- Crosstalk correction
  - Standard ERSDAC software see Iwasaki* for algorithm details

- VNIR and SWIR re-sampled into single 30m dataset

- Conversion to exo-atmospheric reflectance
  - Solar irradiance, sun zenith

\[ \rho_p = \frac{\pi \cdot L_\lambda \cdot d^2}{E_{\text{SUN},\lambda} \cdot \cos \theta_S} \]

*Iwasaki & Tonooka (2005) Validation of Crosstalk Correction Algorithm fo ASTER/SWIR. IEEE TRANS ON GEOSCIENCE AND REMOTE SENSING, VOL. 43, NO. 12, DECEMBER*
Workflow considerations

• ASTER Instrument Effect – Crosstalk
  • Leakage of photons from band 4
  • Caused by multiple reflections between aluminum coatings in detector
  • Effects all bands but most apparent in bands 5 and 9
  • Additive, spatially varying effect
  • ERSDAC software available which partially compensates for effect. Residual effects can remain
Methodology – Overview (continued.)

• Cross scene calibration
  • CSIRO in-house developed calibration software*
  • Developed by group that established calibration techniques for Australian continental Landsat mosaic
  • Empirical approach utilising statistics of invariant sites in the areas of scene overlap to calculate per scene per band calibration coefficients.
  • Semi automated approach.

Methodology – Overview (continued.)

• Calibration to apparent surface reflectance
  • ASTER mosaic calibrated to Hyperion data;
  • Australian archive of 18 Hyperion scenes processed to apparent surface reflectance and used as reference;
  • Least squares regression using 422 invariant targets;
  • Calibration curves with $R^2$ 0.77-0.91 for each band established
Methodology – Overview (continued.)

• **Information Extraction – Mineral Mapping**
  - Ratios and continuum band ratios used to identify geoscience information e.g.
    - \((B5+B7)/B6\) = AlOH group abundance
    - \(B5/B7\) = AlOH group composition etc.
    - \(B4/B3\) = Ferric oxide abundance
  - Robust measures which normalise out topographic differences
  - Ratios map absorption features specific to mineral groups
  - Geoscience products further refined by masking for green veg, cloud, water bodies and recent fire scars

**Version 1 ASTER Geoscience products**

A set of ~14 GIS-compatible mosaics generated from 3,600 ASTER scenes.

**VNIR-SWIR products include:**
- False colour
- Green vegetation content
- Regolith ratios
- Ferric oxide content
- Ferric oxide composition
- Ferrous iron content
- Opaque index
- AlOH group content
- AlOH group composition
- Kaolin group index
- FeOH group content
- MgOH group content
- MgOH group composition
- Ferrous iron content in MgOH

**TIR products**
- Silica index
- Quartz index
- Gypsum index
7. Opaque index (potentially includes carbon black (e.g. ash), magnetite, Mn oxides, and sulphaides in unoxidised environments)

<table>
<thead>
<tr>
<th>Product name (in red)</th>
<th>Base algorithm B=band No. = band No.</th>
<th>Masks</th>
<th>Stretch^ (lower limit)</th>
<th>Stretch^ (upper limit)</th>
<th>Stretch^ type</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Opaque index</td>
<td>B_1/B_4</td>
<td>Thick cloud* + sun glint* + B_4 &lt;2500 + green vegetation &lt;1.75</td>
<td>0.4 Blue is low content</td>
<td>0.9 Red is high content</td>
<td>linear</td>
</tr>
</tbody>
</table>

Accuracy: Moderate: Complicated by “albedo” effects, cloud shadow and recent fires scars (high black ash content), smoke, other vegetation changes and any residual errors in aerosol correction. The complications with albedo arise for example with iron-oxide poor materials/pixels, such as quartz and/or clays that are equally bright at VNIR- and SWIR wavelengths. These are isolated (in part) using the albedo mask (<25%), though this can be further complicated by “shadowing” effects, e.g., clay rich pixels in shade. This product needs to be compared with the albedo and false colour infrared products to help isolate these and other complications.

Geoscience Applications*: Useful for mapping:
(1) magnetite-bearing rocks (e.g. BIF); (2) maghemite gravels; (3) manganese oxides; (4) graphitic shales.

Note 1: (1) and (4) above can be evidence for “reduced” rocks when interpreting REDOX gradients. Combine with “AIH Group Content” (high values) and Composition (high values) products, to find evidence for any invading “oxidised” hydrothermal fluids which may have interacted with reduced rocks evident in the Opaques index product.

8. AIH Group content (phengite, muscovite, paragonite, lepidolite, illite, brammalite, montmorillonite, beidellite, kaolinite, dickite)

<table>
<thead>
<tr>
<th>Product name (in red)</th>
<th>Base algorithm B=band No. = band No.</th>
<th>Masks</th>
<th>Stretch^ (lower limit)</th>
<th>Stretch^ (upper limit)</th>
<th>Stretch^ type</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. AIH Group content</td>
<td>(B_5+B_7)/B_6</td>
<td>Composite mask* + green vegetation mask &lt;1.75</td>
<td>1.95 Blue is low content</td>
<td>2.4 Red is high content</td>
<td>linear</td>
</tr>
</tbody>
</table>

Accuracy: Moderate: From laboratory validation studies of WA geological samples (Haest et al, 2012 Economic Geology), the RMSE of this product is ~5%. However, this error is larger for these Version 1.1 ASTER products, given that there is no correction for mixing with green and dry vegetation.

Accuracy is complicated by any minerals with absorption at B_5 and/or B_7, such as: (a) abundant well-ordered kaolinite, which will show only a small relative absorption depth (abundance) at B_6 because it also absorbs strongly at B_5; and (b) mixing of an Al-OH clay with B_7 absorbing minerals like chlorite/epidote; and (c) mixing with green/dry plant materials.

Note 1: Later ASTER images (~2007) began to develop an instrument problem associated with decreasing dynamic range and related detector saturation for brighter pixels causing the SWIR module finally decommissioned from 2008. Evidence of this degradation is apparent in the current mosaic for some of the 2007 scenes especially for products involving B_6 and for pixels/areas with high albedo. After normalisation, these compromised areas are effectively reduced to column striping only. Ideally these scenes should be replaced.

Geoscience Applications*: Useful for mapping:
(1) exposed saprolite/saprock
(2) clay-rich stratigraphic horizons;
(3) lithology-overprinting hydrothermal phyllic (e.g. white mica) alteration; and
(4) clay-rich diluents in ore systems (e.g. clay in iron ore).

Also combine with AIH composition to help map:
(1) exposed in situ parent material persisting through “cover” which can be expressed as: (a) more abundant AIH content; + (b) long...
Minerals

View the ASTER maps using World Wind
View and download ASTER maps:
- http://portal.auscope.org/portal/gmap.html;
- http://geoscience.nt.gov.au/giws or
- https://datanet.csiro.au/dap/landingpage?execution=e1s2 & eventld=viewDescription

Silicate index
low high

Eastern Arunta Inlier
The journey

October 2010 TC diagnosis of Waldenstrom’s Macroglobulinemia

Chemotherapy
6 months

Pulmonary embolism

Chemotherapy
3 months

Early 1990s, Gabell and Cudahy on ASTER science team

September 2012 launch of Min Map of Oz at IGC

1999 launch of ASTER

2009 ASTER archive of OZ, 35K scenes, 75% cloud free

Life’s a journey, not a destination. Steve Tyler, American Musician 1948
Building upon our pass: Viewing across the surface and into the earth through time

When you arrive at your destination, pay absolutely no attention to the thing people call jetlag.
Lara St John, 1971 (Canadian Musician)
National Virtual Core Library
National Geochemical Survey of Australia (NGSA).

- Geoscience Australia + State and Territory Geological Surveys
- Gap = no National geochemical coverage
- Transported regolith samples at the outlet of large catchments
- Two depths: 0-10 cm; 60 and 80 cm
- 1390 catchments covering 91 per cent of Australia
- 60 elements using mainly XRF and collision cell ICP-MS + particle size, pH, LOI, etc.
Broken Hill Survey

- 150 Gigabytes of airborne HS data collected in 2002 for GSNSW
- L1b and L2 products made publicly available but only 1-2 copies downloaded
- C3DMM processed to L3 mineral maps in 2009
- together with other C3DMM data, over 60,000 products downloaded
Continental scale mineral mapping using ASTER data

http://portal.auscope.org/portal/gmap.html
Use of ASTER mineral map to identify iron ore deposit
Airborne hyperspectral mineral maps
Clay composition – spectra & XRD

In collaboration with Murchison Metals
Iron oxide content – spectra & XRF

Fe-ox ab. > 1.175

Fe-ox abundance

Drill cores: 1.0 1.175

Fe-oxide shell: 0.0 45.0

>45 Wt% Fe
Access of ASTER geoscience maps


http://geosspubregistries.info/geossreg/
Thank you

CSIRO Earth Science and Resource Engineering
Carsten Laukamp
Geoscientist

+61 8 6436 8754
carsten.laukamp@csiro.au
http://c3dmm.csiro.au/

Western Australian Centre of Excellence for 3D Mineral Mapping/ MDU Flagship
References


• Haest, M., Cudahy, T., Laukamp, C., Gregrory, S. (2012): Quantitative mineralogy from visible to shortwave infrared spectroscopic data - II. 3D mineralogical characterisation of the Rocklea Dome channel iron deposit, Western Australia - Economic Geology, 107, 229 - 249.